**Morphemic Processing in Chinese Children: Evidence from Eye-Fixations**

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## Abstract

The present study aims to explore the validity of the Visual World Paradigm in unveiling the mechanisms of morphemic and speech processing in Chinese children. Two experimental sessions were conducted on 2nd and 5th graders in Hong Kong. Two-character words that shared an ambiguous character with the same sound but different morphemes (e.g. "教師" or "教堂", the first character can mean either "teaching" or "religion") were uttered and subjects performed a target-detection task with either pictures or printed words, and their eye-movements were measured simultaneously. This newly established paradigm successfully yielded reliable and valid data in Chinese children. Results showed that while both 2nd and 5th graders were capable of utilizing the morphemic mode of processing, their efficiency in resolving morphemic ambiguities differed. Second graders were poorer in suppressing fixations to the morphemic competitor, and needed longer time to reach peak fixations towards the target word. Furthermore, our manipulation of morphemic dominance produced a weak facilitating effect on 5th graders but not on 2nd graders. Implications of these findings to literacy studies of morphological awareness and existing models of morphemic processing were discussed.

研究摘要

本研究利用"Visual World Paradigm"探索中國兒童處理中文詞素的過程·實驗分兩部份，參與測試的兒童均在香港就讀二年級或五年級·在測試過程中，測試者將聽到一些發音相同但不同詞素的兩字詞語 (如"教師"和"教堂")，營光幕則同時顯示一些圖片或文字，兒童需要判斷聽到的詞語是否出現在營光幕中·在測試過程中，我們量度兒童的眼球運動數據·本研究成功獲得具效度和信度的數據·實驗結果顯示，二年級和五年級的兒童均可以利用詞素的分析來處理中文詞語；二年級的兒童較難壓抑對同音詞素的注視，以致拖延了其整體辨認詞語的時間·我們亦發現五年級的兒童對高頻詞素的處理會快一點·文中並詳細討論研究結果對詞素處理過程的貢獻·

# Chapter 1: Introduction

How children from all over the world are able to acquire the language spoken around them with ease have puzzled researchers for long. Past researches mostly focused on European languages, and conclusions were often generalized to other languages without examining their specific features. These attempts were challenged by Slobin (1985) and many other scholars, who stressed the need to conduct cross-linguistic researches to tap language-specific processes of acquisition, as he argued that "cross-linguistic study does more than reveal uniformities of development, because properties of individual languages influence the course of development…One cannot study universals without exploring particulars" (p. 4).

The Chinese language is doubtlessly one that merits attention, as it is uttered by 13 billion people around the world, which accounts for approximately 20% of the world population. Chinese is a logographic-based system that differs from most European languages in many aspects (see Chen, 1992; 1996 for discussion). With regard to phonology, Chinese characters represent syllables, rather than phonemes. Unlike English, there are no explicit conversion rules between the print and sound of a Chinese character. Besides, Chinese has a lot more homophones than English, even when tonal information is taken into account. Another salient difference lies in their morphologies. Morphemic information is conveyed by just one character in Chinese, while in English a morpheme is usually mapped onto a few characters. Great discrepancies are also found in the rules of word formation. Inflectional and derivational morphologies are very common in European languages, as word formations are governed by stringent grammatical rules. In Chinese, however, compounding accounts for more than 80% of Chinese words (see Packard, 2000). A compound word may be morphologically transparent or opaque, depending on whether or not its meaning is contributed by the individual character morphemes. Besides information at the character-to-word level, the orthography of Chinese characters also conveys meaning in itself, as shown by their semantic radicals. A few researchers coined these within-character meanings as grapho-morphology (e.g. Nagy, et al., 2002; Ding, Peng & Taft, 2004), though others regarded this as simply a subset of orthography (Shu & Anderson, 1997). These peculiar features of the Chinese language have pointed to the fact that morphemes may play a crucial role in the acquisition of Chinese, and its contributions may be different from that in European languages.

Two different approaches to tapping influence of linguistic units exist in the literature, each of which has attracted numerous scholarly researches over the past few decades. The first adopts an outcome-oriented "awareness" approach, in which the focus is on whether children demonstrate the conscious ability to understand features of a particular linguistic unit, as shown by their performance in oral or paper-and-pencil literacy tasks (see Nagy & Anderson, 1998 for a review). Another cluster of researches tackle the issue from a "processing" perspective, in which the issues concerned hinge on the underlying mechanisms that allow the brain to process a linguistic unit, regardless of whether it results in conscious understanding or not. With regard to the influence of morphemes, studies from both perspectives are reviewed below, and their pros and cons are discussed.

*The "Awareness" Approach to Tapping Influence of Morphemes*

Scholars in the field of language development usually placed the emphasis on tapping meta-linguistic awareness, defined as the awareness to different aspects of the underlying linguistic structure (Nagy & Anderson, 1998; Shu & Anderson, 1999). Among the many linguistic units, phonological awareness, or the awareness to the properties of sounds of a language, has received the greatest amount of attention. The association between phonological awareness and reading in European languages like English has been firmly established (Cunningham, 1990; Foorman, Francis, Novy, & Liberman, 1991; Mann, 1984; 1993; Treiman, 1991).

Prior to the discovery of the importance of morphological awareness, Chinese literacy researchers also followed the established traditions, as they explored the contributions of phonological awareness to reading development (e.g. Ho & Bryant, 1997; Shu & Anderson, 1999; Mcbride-Chang & Kail, 2002). Like English, significant associations were found in those empirical studies, though awareness at the syllabic level, rather than phonemic level, appeared to be more important. Cheung, Chen, Lai, Wong and Hills (2001) also discovered that phonological awareness depend on the presence or absence of explicit instructions provided (known as "Pin-yin" training) in school. While phonological awareness certainly has its role in Chinese language acquisition, the story does not seem to end there.

A bunch of studies emerged in recent years to dig out the variance left unaccounted for in Chinese reading development. Morphological awareness was what they discovered. Mcbride-Chang, Shu, Zhou, Wat and Wagner (2003), for example, administered various meta-linguistic tasks to 5 and 8-year-old Chinese children and found that two tasks tapping morphological awareness uniquely predicted character recognition over and above phonological awareness six months later. Mcbride-Chang et al. claimed that phonological awareness alone would not suffice in Chinese character recognition, as it cannot effectively eliminate the competing homophones sharing the same sound. With an interest on dyslexic children, Shu, Mcbride-Chang, Wu and Liu (2006) also revealed that performance on morphological awareness tasks successfully distinguished Chinese children with and without being diagnosed of dyslexia. Studies comparing children of different countries also yielded convergent results (e.g. Ku & Anderson, 2003; Mcbride-Chang, et al., 2005a). These researchers discovered that the strength of association of morphological awareness to reading was much greater among the Asian children learning to read an orthographical script, than the

English-speaking children in USA. Instead of measuring morphological skills at a single time-point, Nagy et al. (2002) went a step further by conducting a one-year intervention study, aimed at training the morphological skills of children in Beijing, China. Comparison of the pre-post test scores indicated that students not only performed better on tasks of morphological awareness, but also on character recognitions skills. In similar vein, Packard, et al. (2006) conducted training programs for Chinese first graders and found that it boosted their writing performance.

Various literacy tasks have been constructed to tap morphological awareness in Chinese children. Researchers generally distinguished between "implicit" and "explicit" measures of morphological awareness (Mcbride-Chang, 2004). How the measurements are taken is described in detail below.

In "implicit" tasks, children are only required to apply morphological knowledge to make judgments, often in a forced-choice situation. Perhaps the commonest one is the morphological discrimination task (e.g. Li, Anderson, Nagy & Zhang, 2002; Ku & Anderson, 2003; Nagy, et al., 2002), in which a few words sharing the same morpheme were presented at a time, and children were to select the "odd" one out, based on whether the morpheme has a different meaning than others in the word context. Thus, when provided with the Chinese words "商人" (businessman), "商店" (shops) and "商量" (negotiation), the correct answer would be"商量". Some other tests like morphemic judgment (i.e. judging if the morpheme has equal meanings in two words) and select interpretations (i.e. judging the correct interpretation of the morpheme in the word) also followed similar logics but differed somewhat in the way of prompting an answer (see Ku & Anderson, 2003). These tasks are applicable to most elementary school children, as Ku and Anderson found that correct rate ranged from around 50% in Grade 2 students to 80% in Grade 6 students. For younger children like kindergarteners, due to their poorly developed orthographical knowledge, these tests are usually administered orally with pictorial aids. In the Morphological Identification Test (e.g. Li, et al., 2001; Mcbride-Chang, et al., 2003), for example, three pictures depicting words that share a homophone are shown. The three words are uttered followed by a prompting word, which also shares a homophone with the three words. Children have to judge which of the three words best corresponded to the meaning of the homophone in the prompting word. An example would be 籃球 (basketball), 男孩 (boy) and blue (藍色), with the prompt "男女" (boy-girl) (Mcbride-Chang, et al., 2003). In that case, the child should point towards the picture denoting a boy (男孩).

On the other hand, "explicit" tasks would require the active manipulation of morphemes in novel situations. Berko (1958) was the first to develop items to tap such skills in children. One of his famous items was, "There is a wug. Now there is another one. There are two of them. There are two _____" Since "wug" is a pseudo-word, the child would not be able to retrieve its meaning, though he could still apply the rules of inflections by adding an "s" after it to yield a correct response. Following Berko's approach with emphasis on compound morphologies, the Morphological Construction Task was developed and applied to the Chinese population recently (Chow & Chow, 2005; Mcbride-Chang, et al., 2003; 2005a). Children are first taught how the meaning of a word is related to its morphemes, and are then asked to construct a new word based on the compounding rules presented. An example item would be "If we see a sun rising in the morning, we call it a sunrise (日出). What should we call the phenomenon of moon rising? The correct answer would be moonrise (月出)" (see Mcbride-Chang, et al., 2003). Hence, to tackle the task children would not only need to be aware of the meaning of the morphemes, but also to discover and apply the rules of compounding to form new words. With 20 Chinese items administered to local kids, Mcbride-Chang et al. (2003) found the accuracy rate of kindergarteners and Primary 2 students to be 55% and 80% respectively. Chow and Chow (2005) further analyzed the error responses of kindergarteners, and concluded that morphological awareness involved the component skills of selecting the target morphemes, combining them in proper orders and inhibiting the competitors. Cross-cultural studies revealed that native English speakers performed much poorer in this aspect, as their K3 and P2 kids only answered 40% and 60% of the items correctly (Mcbride-Chang et al., 2005b).

*Inadequacies of the "Awareness" Approach*

The recent trend in Chinese reading research appears to be heading towards the right direction, when morphological awareness is entered into the picture. Though, the previous studies also left some issues hanging in the air.

My first concern rests on the validity of the existing morphological awareness tasks. For the "implicit" tasks, a problem is that morphological awareness at the character-to-word level may be confounded with awareness to the overall meaning of the compound word. For example, in the morphological discrimination task, children may first retrieve the meaning of the words, and then by comparing their strength of semantic associations with each other, the word bearing weak semantic linkages with others would "pop out". Hence children can perform the task as accurately without the need to decompose words into morphemic units. This problem is somewhat elevated when pictures are used in the Morphological Identification Test (Mcbride-Chang, et al., 2003; 2005a), as pictorial cues would then directly trigger semantic processing of relevant concepts, again bypassing the bottom-up morphemic processing of characters. Even Mcbride-Chang et al. (2005a) admitted that "this task may have tapped semantic association knowledge in its use of pictures (p. 423)". Besides, using homophones without controlling for orthography (e.g. Mcbride-Chang et al., 2003) also appear problematic. Though the tasks are orally administered, the possibility that the child retrieves the orthography of the characters and applies orthographical skills for making decisions cannot be ruled out. For the "explicit" tasks, one major concern is that the "example" and probing question may easily cue the children to make a correct response, regardless of their prior morphological awareness skills. Hence, the task may serve "instructional", rather than "measurement" purposes. Children may also be perplexed by having to produce non-words (e.g. 月出). They may treat these non-words as wrong answers, as it does not exist in their mental lexicon.

My second concern hinges on the mental processes that contribute to the outcome of developing morphological awareness. While much has been known regarding the importance of morphological awareness to various aspects of reading development in Chinese, there are very limited understandings as to the underlying mechanisms behind children's analysis of morphemes. For example, how do children resolve morphemes when they encounter ambiguities (i.e. alternative explanations available)? Do they rely on context for disambiguation, or do they make a "bet" by committing to the more frequently used one? These questions still await to be addressed.

Yet another concern lies on the interpretation of grade difference in morphological awareness. Grade differences were reported in some previous studies (e.g. Mcbride et al., 2003; Nagy & Anderson, 2003), but often times they were trivially interpreted as differences in amount of reading exposures. These researchers might have apparently overlooked the influence of cognitive constraints that may hamper performance of young children.

*The "Processing" Approach to Tapping Influence of Morphemes*

The weaknesses of literacy tasks and the lack of process-oriented accounts have put forth the need to examine the influence of morphemes from a "processing" perspective. There had been a long research tradition in Psycholinguistics to tackle these issues with well-controlled paradigms in adults, which researchers coined as "morphemic processing".

In adults, experimental evidences on the importance of morphemes in word recognition were mainly accrued from findings on the morphemic dominance effect (e.g. Baayen, Dijkstra & Schreuder, 1997; Cole, Beauvillain & Segui, 1989; Feldman, Frost & Pnini, 1995; Taft, 1979). Using paradigms like primed lexical decision, in which reaction time was measured as subjects judged if the target is a word, these researchers consistently found that a high-frequency stem (e.g. room) facilitated subsequent recognition of a poly-morphemic word with that stem (e.g. bathroom), even when overall word frequency was controlled for. This led Taft (1994; 2004) to propose an interactive-activation model that encompasses a separate representation for "morphemes" in our mental lexicon, to which some researchers later called the "lemma" level of representation (Schreuder & Baayen, 1995). In Taft's model, access from phonology or orthography to concepts must be mediated by access to morphemes at the lemma level. Hence, poly-morphemic English words are not represented as a whole, but decomposed as morphemes in the mental lexicon (Taft, 2004).

Some recent studies also addressed the representation of morphemes in Chinese. For example, the morphemic dominance effect was successfully replicated in Chinese at the character-to-word level, as character morphemes with high frequency facilitated response to morphologically transparent words (Peng, Li, Li & Liu, 1999; Wang & Peng, 1999; Taft & Zhu, 1995). These researchers were cautious that their findings might confound with orthographic processing, and thus devised careful procedures to eliminate them. For example, Peng et al. (1999) found that word primes that shared both the same orthography and morpheme showed greater facilitation than those which shared only the form. Hence, if the target word is "華麗" ("magnificent"), the prime "華貴" ("luxurious") would be more effective than "華人" ("Chinese people").

Besides unveiling the role of morphemes as a core representation unit in the mental lexicon, some other researchers also approached from a different angle and explored how morphemes with ambiguous meanings are selected and retrieved for semantic integration. This line of research also had a long tradition and various "access" models have been proposed over the past two decades. All of these models identified two crucial factors, namely meaning dominance and effect of context, but differed in how they influence the process of ambiguity resolution. For example, some believed that all meanings are activated at the same time (e.g. Swinney, 1979) while others conjectured that only one of them can be accessed at a time (e.g. Simpson, 1981; 1984). Besides, whether meaning dominance and contexts affect lexical access concurrently (e.g. Rayner & Duffy, 1986; Rayner & Frazier, 1989) or in a stepwise manner (e.g. Forster & Bednall, 1976) is still an unresolved issue to date. Some recent debates also centered on the interactions between the two factors, as a function of context strength (Binder & Rayner, 1998;see Kellas & Vu, 1999 for alternative viewpoints).

Studies using experimental paradigms to tackle morphemic processing in Chinese children are extremely scarce, Li's (2005) study was the only exception thus far. Following the research tradition in adults, Li used a primed lexical decision task to tap morphemic processing in Chinese elementary school children. Primes sharing the same morpheme with the target were presented to see if they facilitated subsequent recognition of the target word. Li also adopted Peng et al. (1999) approach to remove confounds with other linguistic processes, by introducing primes which share only semantic (i.e. the "semantic" condition) and orthographic information (i.e. the "orthographic" condition) with the targets. The test was administered to normal 2$^{nd}$ and 5$^{th}$ graders in Hong Kong. Results showed that 5$^{th}$ graders produced faster reaction time and lower error rate than 2$^{nd}$ graders in the "morphemic prime" condition. Within each age group, the effect size of morphemic prime in 5$^{th}$ graders was greater than the 2$^{nd}$ graders, as only 5$^{th}$ graders yielded significant differences between conditions. These results hence revealed increasing ability to process morphemes with age, which stood in line with findings using the "awareness" approach (e.g. Ku & Anderson, 2003; Mcbride-Chang, et al., 2003). More strikingly, Li analyzed the role of proficiency and discovered that good readers also responded faster and more accurately than poor readers. In addition, there was an interaction between proficiency and prime type, with good readers responding quicker in the morphemic than semantic or orthographic conditions, whilst poor readers failed to show significant differences between conditions. These results further strengthen the belief that the morphemic mode of processing are characteristic of good readers and that they can be dissociated from semantic and orthographic processes.

*Measuring Eye Movements in Linguistic Research*

While findings using reaction time measures are robust, they are often criticized as of low external validity, as measurement is often not taken out of a context mimicking real listening or reading comprehension. We rarely would encounter situations like making a word-or-non-word decision upon being primed in daily life. Hence, many literacy researchers remained skeptical towards applying those paradigms to tap morphological awareness in children.

That prompts us to explore another newly emerging online measure, namely the measurement of eye-movements, which is able to precisely capture the moment-by-moment linguistic processes in a natural context. In the field of Psycholinguistics, there had been 30 years of researches with eye-movement measures (see Rayner, 1998 for review). Human eye-movements are characterized by fixations (the pupil is static) and saccades (the pupil is moving). When reading written texts, visual information can only be gathered during fixations, but not saccades (Rayner, 1978). The location and duration of each fixation thus provide clues for researchers to infer the underlying linguistic processes taking place. Recent theoretical and methodological advancement have also extended its use to the verbal modality.

Allopenna, Magnuson and Tanenhaus (1998) were among the first to theorize how eye-movements can be used to tap comprehension processes in spoken texts. They proposed the linking hypothesis, which states that the probability of fixating an object with the eyes reflects the activation level of that object in the mental lexicon. As the name of the object is gradually unfolded, fixations will be increasingly diverted towards the visual representation of the object. However, this does not happen in an all-or-none manner. Rather, partial information can also attract fixations to other phonologically similar competitors. In Allopenna et al. study, for example, when the target word "beaker" was uttered, the cohort "beetle" also received high proportions of fixations in the beginning, as it shared the initial syllable with the target.

In addition to the establishment of a theoretical framework, the development of a ground-breaking paradigm called "Visual World" (Tanenhaus, Spivey-Knowlton, Eberhard & Sedivy, 1995) also helped popularize the use of eye-movement technique on spoken text comprehension. In their original study, Tanenhaus et al. presented spoken instructions telling participants to move objects in a visual display, and their eye-movements were recorded as instructions were comprehended. With an interest in tapping syntactic ambiguity resolution, the instructions were carefully manipulated such that they can be syntactically parsed in two different ways, resulting in a "garden-path" sentence (Frazier, 1987). The goal of their study was to determine if the non-linguistic visual context could bias participants to activate one syntactic parsing strategy in favor of another. Their eye-movement data suggested so. The task was later administered to 5-year-olds (Trueswell, Sekerina, Hill & Logrip, 1999). Reliable eye-movement data were gleaned and implications to the adult literatures were also addressed.

Following the pioneering work of Tanenhaus et al. (1995), the Visual World paradigm has also seen success in tackling issues in sentence processing. For example, Altmann and colleagues (Altmann & Kamide, 1999; Kamide, Altmann & Haywood, 2003; Huettig & Altmann, 2004) investigated the mechanisms of semantic integration in sentence processing. Participants looked around four pictures as they heard a sentence with a target word preceded by a biasing context, produced either by manipulating the preceding verb (Altmann & Kamide, 1999), the subject (Kamide, Altmann & Haywood, 2003) or the whole sentence (Huettig & Altmann, 2004). Eye-movements of participants were clearly affected by such manipulations, as they made more saccades and produced longer fixations towards the picture of the target word, even before the word itself was heard. More strikingly, Nation, Marshall and Altmann (2003) successfully replicated the findings in 11-year-old children, as regardless of whether they are skilled readers or not, they showed anticipatory eye-movements when a biased verb was uttered prior to the target word.

Eye-movement studies on spoken morphemic processing in Chinese were non-existent, until Tsang (2006) recently filled the gap in his Master thesis. With a focus on morphemic ambiguity resolution, he applied the Visual World paradigm similar to that of Marshall and Altmann (2003). Two-character words that shared a common character but different morphemes were chosen. Three pictures were shown, with one of them representing the target word, another the morphemic distracter and the third one an unrelated control. In two experiments, either the target word only or the target word preceded by a sentence is uttered as participants' eye-movements are monitored. The eye-movement data revealed that adults are sensitive to the manipulations of morphemic ambiguity, and their responses were affected by both the frequency of the morphemes and prior context. His study has established the foundation to tap morphemic processing with eye-movement measures in Chinese children.

All in all, these studies have purported to establish the reliability and validity of eye-movement measures in language processing.

*The Present Study*

The present study serves both methodological and theoretical contributions. First, we aim to develop and establish the validity of an experimental paradigm to tap morphemic processing in Chinese children. The successes of the aforementioned eye-movement studies have boosted our confidence towards using this measure in the present study. The recently developed Visual World paradigm also appears well suited to be used among children. The task is simple enough for young children and the attractive visual stimuli can keep them motivated throughout the experiment. The eye-movement and "Visual World" duo are adopted as the experimental paradigm in the present study.

The second objective is to provide process-oriented accounts for the influences of morphemes in Chinese language acquisition, which is seriously inadequate in the literature. Existing adult studies have provided guidance as to the specific questions addressed in this aspect. As in Tsang (2006) study, tapping the processes of resolving ambiguous morphemes in children seem appropriate, as such situations are frequently encountered in Chinese. We examine ambiguity resolution at the word level, rather than at the sentence level, so that differences in comprehension skills can be minimized. Tsang's adult data would serve as the prototype to be contrasted against our findings in children. The present study, taken from a "processing" vantage point, also hopes to inform and enrich the implications accrued from outcome-oriented researches on morphological awareness.

In line with previous researches, we aim to tap morphemic processing mostly in the verbal modality. However, we also want to examine how the introduction of printed texts would affect the processing of morphemes. For older children, printed texts reduce the number of homophonic competitors, hence leading to faster processing time. However, as young children were yet to fully master the orthography of the Chinese language, the demand of orthography skills may serve to interfere their processing efficiency.

Primary school children in Hong Kong are chosen, as they are on the verge of developing competence in the Chinese language. Children of two different grades are selected, so as to maximize possibilities of revealing grade differences in processing morphemes. We follow Li (2005) and select $2^{nd}$ and $5^{th}$ graders for the present study, as Li also examined the issue with experimental paradigms and revealed grade differences.

Using the Visual Word Paradigm with eye fixations as the dependent measure, two experimental sessions on morphemic ambiguity resolution are conducted on Cantonese-speaking $2^{nd}$ and $5^{th}$ graders in Hong Kong. The first session is a replication of the first experiment in Tsang's (2006) study, using a target detection task with pictures as visual stimulus and two-character Chinese words as spoken stimulus. The second session uses written Chinese characters as visual stimulus. The first character of the experimental stimuli is always morphologically ambiguous (i.e. can map onto two different morphemes). Each time one of them would combine with another character to form the target word, and the other competitor would form another word to serve as a morphemic distracter. A morphologically unambiguous control word serves as an unrelated distracter. Children's fixations towards the target word and other distracters are recorded throughout the entire session of each experimental trial. If children are aware of the need to resolve morphemic ambiguity, they would display sensitivity to our manipulations of morphemic ambiguity, and differences in patterns of eye-movements would be observed across different conditions. Also, due to the need to resolve ambiguities, we expect fixations to the morphemic distracters would be temporarily higher than the unrelated distracters. However, if they are yet to develop the ability to process words at the morphemic level, our manipulations would not influence their patterns of eye-movements.

# Chapter 2: Method

*Participants*

Twenty-two 2nd graders *(mean age=7.3, male=12)* and twenty-five 5th graders *(mean age =10.5, male=11)* from mainstream primary schools in Hong Kong took part in the present study. All of them were native Cantonese speakers and could read Chinese characters. They all possessed either normal or corrected-to-normal vision and did not suffer any sensory or neurological impairment. Their parents gave informed consent and were paid HK$60 as remuneration for the traveling cost between CUHK and their living district. Children also received candies and stationeries as rewards. All participants and their parents were naïve to the experimental hypotheses and procedures of the experiment beforehand.

*Control Measures*

Prior to conducting the experiment, a series of literacy measures were administered to ensure that the participants were matched on non-verbal IQ and Chinese language competence, and did not possess symptoms of dyslexia.

The Raven's Progressive Matrices (Raven, 1938) was used as the measure for children's non-verbal IQ. It comprises 60 multiple-choice questions with increasing difficulty, which taps children's analytical reasoning on graphics. For each question, a portion of each figure was removed, and children had to choose the most appropriate figure that fit the space. Four subscales from the Hong Kong Test of Specific Learning Difficulties in Reading and Writing (HKT-SpLD; Ho, Chan, Tsang & Lee, 2000) were adopted for measuring the general cognitive processing skill and Chinese language competence of the two age groups. A speeded-naming task of numbers was administered to tap children's general cognitive processing skills. Participants were timed twice as they read aloud 40 numbers, and the averaged time constituted the raw score of the task. The Chinese character speeded-naming task, the character recognition task and the dictation test were used as measures for language competence. In the character speeded-naming task, participants were given one minute to read 90 two-character words. For the character recognition task, participants had to utter 150 two-character words of increasing difficulties in a self-paced manner. Raw scores were computed based on the number of correct words uttered. For the dictation test, participants had to write 48 two-character words of increasing difficulties. Raw scores were calculated based on the number of correct characters written.

All these scales have been standardized among primary school students aged between six and twelve years old in Hong Kong. Norms for each age are constructed to yield the standard score and percentile of each subject. The standard score was used for matching the non-verbal IQ and linguistic competence between the 2nd and 5th graders in the present study.

*Stimuli and Apparatus*

Two Wintel computers were used, one for stimulus presentation and recording responses, and the other for running the software associated with the eye-tracker system. An Eye-link video-based tracking system with sampling frequency of 250Hz was used for running the stimulus program and recording fixations and saccades of the pupil during stimulus presentation. A 17-inch LCD monitor was used for stimulus presentation.

Sixteen ambiguous Chinese characters that map onto two different morphemes were used to construct a total of 32 two-character words with the ambiguous morpheme always at the first position. For example, the character "教" (gaau6) is ambiguous and it is combined with another character to form two different morphemes, namely "教師" ("教" means "teach" here) or "教堂" ("教" means "religion" here). Another 64 two-character words with unambiguous meanings served as controls. The complete stimulus list is shown in the

Appendix. All these words were selected based on both documentary information and data from pilot testing. First, they were verified against a database containing the 3000 commonest characters in primary school children (HKBU, 2003), which suggested that all the stimuli used in the present study had been learnt by 2nd graders. Second, another 20 2nd graders were asked to read the written words aloud and give a meaning to them, the words would be adopted only if at least 80% of these children uttered them correctly and understood their meaning. These procedures guaranteed that all the stimuli were grade-appropriate for the 2nd graders. To find the dominant meaning for the ambiguous morphemes, age-matched children were asked to freely think of vocabularies associated with the ambiguous morphemes. If children could produce vocabularies of two different morphemes, the more frequently used meaning would be the dominant one. All the stimuli were matched on their orthographic and semantic properties, such as number of strokes, character frequency, character difficulty and self-rated word familiarity. A total of 128 black-and-white pictures representing these words were generated in the first experimental session, while black-and-white words with font-size of 72 were used in the second session. The naming agreements of the pictures were validated among age-matched children and only those reaching at least 80% agreement would be chosen. The auditory stimuli of the words were uttered by a native female adult speaker in a silent environment. To make sure that it synchronized with the eye-movement data, the rate of utterance was carefully controlled at approximately 500ms per character syllable, which resembled the normal speaking rate of an adult.

In each trial, either three pictures or three Chinese words were shown at a time under a white background with a resolution of 640 X 480 pixels. For each experiment, there were three conditions of morphemic ambiguity, namely Dominant, Subdominant and Unambiguous respectively. In experimental trials, the screen always contained the target word uttered and two other distracters. Target words with ambiguous morphemes were uttered in the Dominant or Subdominant condition. In the Dominant condition, the target word uttered reflected the morpheme with dominant meaning, with a morphemic distracter reflecting the morpheme with subdominant meaning and an unrelated distracter. An example stimulus set presented would be “教師 (teacher), 教堂 (church) and 排球 (volleyball)”, and the target word uttered was “教師”. Configurations in the subdominant condition were similar to the Dominant condition, except that the target word reflected the morpheme with subdominant meaning. Using the above example, this time “教堂” would be uttered with “教師” and “排球” serving as distracters. In the Unambiguous condition, the target word did not possess ambiguous morphemes and both distracters did not share any characters with it. In one unambiguous trial, the target word was “電話” (telephone), while the two other distracters were “雨傘” (umbrella) and “白兔” (rabbit). The stimulus set was exactly the same between the Picture and Printed Word sessions, so that direct comparisons of their processing could be made. The three pictures/words were placed in the screen in a triangle or inverted-triangle layout, with the fixation cross situated at the center of the triangle. An example stimulus for the Picture and Printed Word session are shown in Figure 1 and 2 respectively.

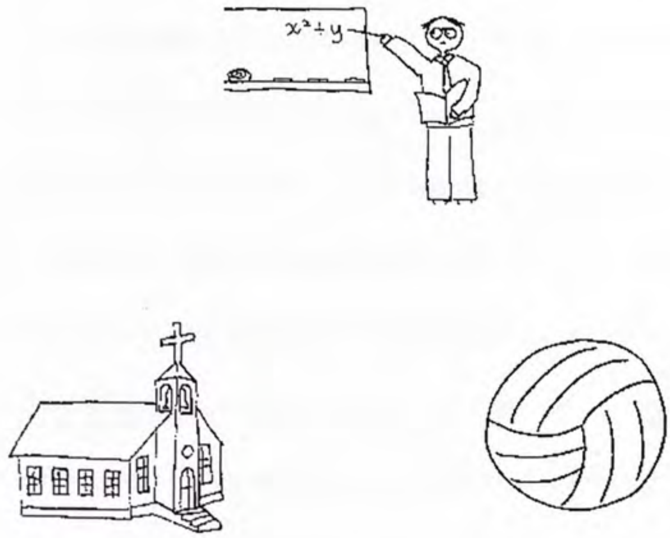


*Figure 1.* Example stimulus in Picture session

教師　　教堂

排球

*Figure 2. Example stimulus in Printed Word session*

*Design and Procedure*

Grade difference (2nd and 5th graders) is the between-subjects factor and there are three within-subjects factors, namely stimulus type (Picture / Printed Word), morphemic ambiguity conditions (Dominant / Subdominant / Unambiguous) and regions of fixations respectively.

Each participant completed two experimental sessions. In the first session, the visual stimuli consisted of pictures while in the second session, the stimuli were two-character

Chinese words. The order of doing the two experimental sessions was counter-balanced across participants. At the beginning of each session, children sat comfortably in front of an LCD monitor with the eye-tracker mounted on their head. They were told not to shake their head and body throughout the entire session, as that would render the eye-movement data unreliable. The camera was adjusted to detect the pupil of their left eye, and then the eye-tracker was calibrated on a 9-point grid so that it could reliably detect and track the pupil location. Participants wearing glasses were told to take them off if they failed in consecutive trials of calibrations. The setup procedure lasted for around 10 minutes. The experimental session then followed. A fixation cross was shown and participants had to fixate at the middle of the cross before proceeding. After a 1000ms delay, three pictures (in Picture session) or two-character Chinese words (in Printed Word session) were displayed on the screen, while utterance of the target word was simultaneously produced in the speaker. Children had to judge if the two-character word uttered could be found in one of the three pictures or words shown. They made the "Yes" or "No" decision by pressing colored buttons on a game pad. Children first completed 8 practice trials to familiarize themselves with the task. There were a total of 32 experimental trials, in which the target word was present and a "Yes" response was expected. To balance the number of "Yes" and "No" responses, we also included 32 filler trials, in which the target word uttered could not be found in any of the three pictures/words shown. Together there are 64 testing trials in each session, which lasts for around 15-20 minutes. Trial order of different morphemic ambiguity conditions was randomized across participants.

*Data Analyses*

Only eye-movement data in the experimental trials were analyzed. Pre-stimulus fixation screens, filler trials, practice trials and trials in which participants made incorrect responses were all discarded. For each experimental trial, there are three region-of-interests (ROI) for capturing the fixations, covering the three pictures or words displayed. Each of these ROI occupies an area of 200 X 200 pixels on the screen. The raw data of each session was first inspected, and fixations that fell just outside the ROI were manually adjusted back to within the region. After corrections on fixations locations, an Excel program was used to calculate the proportion of fixations to each ROI at every 100ms interval, up till 2000ms, when most of the participants should have responded. The absolute time it takes to reach 80% fixations on the target for each trial were interpolated linearly from the fixation curve, using the Goalseek function in Excel. Fixations data of each trial were then aggregated according to the experimental conditions for graphical display and inferential analysis.

# Chapter 3: Results

*Literacy Tasks*

Prior to reporting major findings of the eye-movement data, we report analysis of control measures, which show that the 2nd and 5th graders were matched on IQ level and reading proficiency, after their "maturational" differences were eliminated. Such elimination is achieved through the conversion of their raw scores to standard scores, using norms that are separately constructed for each grade. All measures in the present study are equipped with this conversion procedure, hence allowing meaningful comparisons between the two groups.

The Raven's non-verbal IQ scores of participants ranged from 90 to 120, which were all within the average or above-average level. Standardized mean score of the 2nd and 5th graders were 106.6 and 103.2 respectively, and the difference was not significant, $t(43) = 1.40$, *ns*.

The HKT-SpLD test was used to screen out children with dyslexic symptoms in the present study. According to Ho et al. (2000), an individual is diagnosed as having dyslexia if he/she satisfies BOTH of the following criteria:

(1) *Standardized composite score of Chinese language* $<= 7$

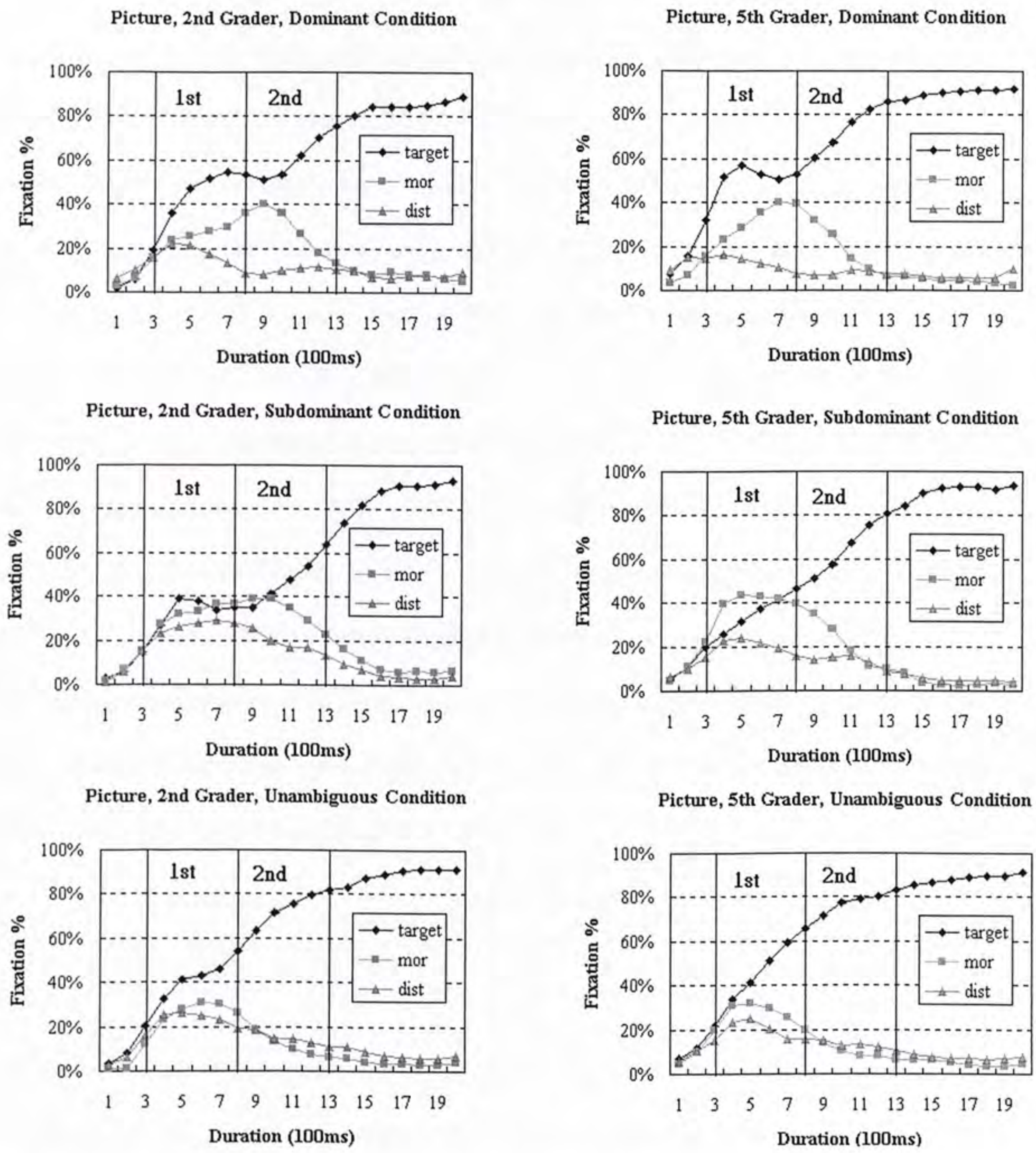
(2) *Standard score of at least one cognitive processing test* $<= 7$

In the present study, the standardized composite score is computed by averaging the score of Chinese character speeded naming, character recognition and dictation test, whereas the number speeded-naming test serves as the measure for cognitive processing. Using the above criteria, data from one 5th grader and one 2nd grader were discarded from the present study. For the remaining students, the standardized composite score of Chinese language competence did not differ significantly between grades, *mean(2nd grader)=10.08, mean(5th grader)=10.53*, $t(43) = 0.62$, *ns*. The standard score of speeded naming task didn't yield a significant grade difference either, *mean(2nd grader)=10.01, Mean(5th grader)=10.44, t(43) = 0.54, ns.*

*Experimental Session 1 (Picture)*

In line with Matin, Shao and Boff' (1993) suggestions and Tsang (2006) study, we believe that children used the first 200ms to plan their saccades, hence fixations at the 100ms and 200ms interval were not analyzed. As utterance duration of each character was controlled at approximately 500ms, fixations of 300-800ms and 800-1300ms reflected the time course of processing the first and second character of the target word respectively. Data points in these intervals were aggregated and the average fixation proportion values were further subjected to analyses of variance (ANOVA) by the within and between-subjects factors. The time periods beyond 1300ms were also not analyzed, as the utterance is finished and children should have reached peak fixations towards the target word by then.

Figure 3 displayed the proportions of fixations for 2$^{nd}$ graders and 5$^{th}$ graders in each of the three conditions, plotted against time intervals. Visual inspection of the graphs revealed striking differences in fixation proportions between the three conditions. In the Dominant and Unambiguous conditions, fixations to the target rose up and separated from the distracters as early as when the first character was being processed. In the Subdominant condition, however, fixations to both the target and the morphemic distracter were high until after the second character is uttered. While the overall patterns of such condition effect looked similar across grades, the curves of the 5$^{th}$ graders were generally displaced leftward to that of the 2$^{nd}$ graders.




Note: Target = The Correct Word, Mor =Morphemic Competitor, Dist=Unrelated Distracter

*Figure 3.* Overall fixation proportions of 2nd graders and 5th graders in the Picture session.

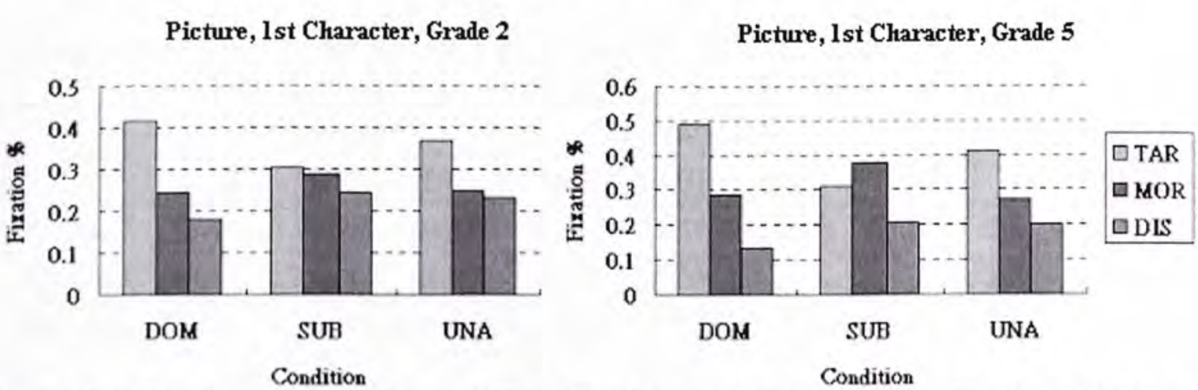
A three-way split-plot ANOVA, treating Condition (three levels) and Fixation Region (three levels) as within-subjects factors and Grade as the between-subjects factor, was conducted on fixation proportions in the first character stage (i.e. 300-800ms). The main effect of Region was highly significant, $F(2,90) = 75.088$, $MSE = 2.374$, $p<.001$. Of greater importance, however, was the significant Condition X Region interaction, $F(4,180) =$

*18.071, MSE = 0.775, p<.001.* Post-hoc paired-sample t-tests revealed that for both 2nd and 5th graders, the target received significantly greater amount of fixations than the morphemic distracter in the Dominant, *2nd grader: t(20) = 4.325, p<.001; 5th grader: t(20) = 5.859, p<.001* and Unambiguous conditions, *2nd grader: t(20) = 3.665, p<.01, 5th grader: t(20) = 3.743, p<.001*, but not in the Subdominant condition, *2nd grader: t(20) = 0.536, ns, 5th grader: t(20) = 1.86, p>.05.* With regard to grade differences, the main effect of Grade was significant, *F(1,45) = 4.802, MSE = .036, p<.05)* , and so did the Region X Grade interaction, *F(2,90) = 5.51, p<.01.* However, the Condition X Grade, *F(2,90) = .778* and Condition X Region X Grade interaction, *F(4, 180) = 1.215* didn't approach significance. To figure out the source for a significant Region X Grade interaction, post-hoc independent-sample t-tests revealed that 5th graders had significantly higher proportions of fixations towards the morphemic distracter, *t(43) = 3.207, p<.01*, but no such grade differences were found on the target and unrelated distracter. The mean fixation values and the corresponding bar chart are shown in Table 1 and Figure 4 respectively.

| | Dominant | | | Subdominant | | | Unambiguous | | |
|---|---|---|---|---|---|---|---|---|---|
| | TAR | MOR | DIS | TAR | MOR | DIS | TAR | DIS | DIS |
| Grade 2 | 41.6% | 24.6% | 17.9% | 30.4% | 28.9% | 24.4% | 36.7% | 24.9% | 23.2% |
| Grade 5 | 48.8% | 28.7% | 13.5% | 31.0% | 38.0% | 20.5% | 41.3% | 27.5% | 20.0% |

*Note: TAR=Target, MOR=Morphemic Distracter, DIS=Unrelated Distracter*

*Table 1. Mean fixation proportion values in the Picture session, 1st character stage.*




Note: DOM=Dominant, SUB=Subdominant, UNA=Unambiguous, TAR=Target, MOR=Morphemic Distracter, DIS=Unrelated Distracter

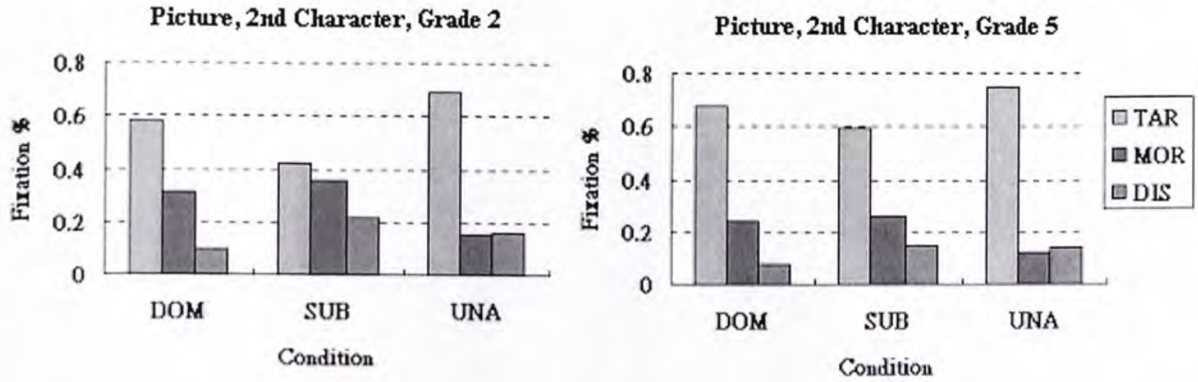
*Figure 4.* Mean fixation proportion values in Picture session, first character stage

Another three-way split-plot ANOVA with Conditions and Regions as the within-subjects factors and Grade as the between-subject factor was conducted on fixation proportions at the second character stage (i.e. 800-1300ms). The results were generally comparable to that in the first character stage, with a significant Region main effect, $F(2,90) = 184.61, MSE = 16.055, p<.001$, Condition X Region interaction, $F(4,180) = 30.369, MSE = 1.814, p<.001$ and Grade X Region interaction $F(2,90) = 11.088, MSE = .964, p<.001$. However, the main effect of Grade now became non-significant, $F(1,45) = .017, ns$. The Condition main effect and its higher order interactions with Grade also failed to reach significance. Post-hoc pair-sampled t-tests again showed that both the second and 5th graders had significantly higher amount of fixations on the target than the morphemic distracter in the Dominant, $2^{nd}$ *grader:* $t(20) = 3.035, p<.01$; $5^{th}$ *grader:* $t(23) = 8.262, p<.001$ and Unambiguous condition, *2nd grader:* $t(20) = 7.271, p<.001$; $5^{th}$ *grader:* $t(23) = 16.545, p<.001$. However, grade difference was revealed in the Subdominant condition. While the 5th graders fixated more on the target, $t(23) = 6.306, p<.001$, the difference could not approach significance in the $2^{nd}$ graders, $t(20) = .977, ns$. On the whole, the target received higher amount of fixations from $5^{th}$ graders than $2^{nd}$ graders, $t(43) = 3.667, p<.01$, but the reverse pattern was observed for the morphemic distracter, $t(43) = -3.164, p<.01$, and the unrelated distracter, $t(43) = -2.527, p<.05$. The mean fixation values and the corresponding bar chart are shown in Table 2 and Figure 5 respectively.

| | Dominant | | | Subdominant | | | Unambiguous | | |
|---|---|---|---|---|---|---|---|---|---|
| | **TAR** | **MOR** | **DIS** | **TAR** | **MOR** | **DIS** | **TAR** | **DIS** | **DIS** |
| **Grade 2** | 55.0% | 35.6% | 10.6% | 40.6% | 35.2% | 23.0% | 65.3% | 19.1% | 16.4% |
| **Grade 5** | 68.1% | 23.9% | 8.1% | 58.5% | 26.5% | 14.7% | 74.0% | 12.7% | 13.6% |

*Note: TAR=Target, MOR=Morphemic Distracter, DIS=Unrelated Distracter*

*Table 2.* Mean fixation proportion values of Picture, second character stage.



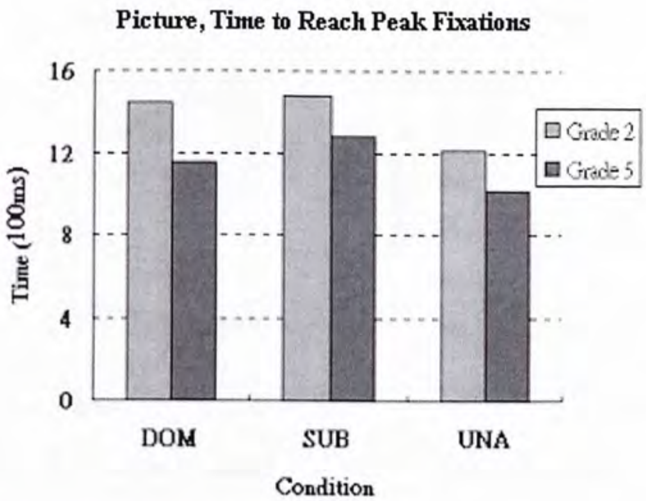

Note: DOM=Dominant, SUB=Subdominant, UNA=Unambiguous, TAR=Target, MOR=Morphemic Distracter, DIS=Unrelated Distracter

*Figure 5.* Mean fixation proportion values in Picture session, second character stage

To examine if there are differences in the overall processing time of the target word in different conditions and grade, a two-way split-plot ANOVA with Condition as the within-subjects factor and Grade as the between-subjects factor was conducted on the time in which the target fixation reached 80%. The main effects of Condition, $F(2,90) = 20.444$, $MSE = 179.811$, $p<.001$, and Grade, $F(1,45) =16.453$, $MSE = 188.966$, $p<.001$, were significant, but their interactions were not, $F(2, 90) = .727$, $MSE = 6.398$, *ns*. Fifth graders were faster in reaching the 80% target fixation point than 2$^{nd}$ graders. Post-hoc t-tests revealed that children of both grades needed the least amount of time in the Unambiguous condition, as compared to the Dominant, $t(43) = 4.059$, $p<.01$, and the Subdominant conditions, $t(43) = 6.362$, $p<.001$. However, while 5$^{th}$ graders required less time to reach peak fixation in the Dominant condition than Subdominant condition, $t(23) = 2.859$, $p<.01$, the difference was not significant for 2$^{nd}$ graders, $t(20) = .566$, *ns*. Table 3 and Figure 6 present the mean values and graphs of this measure.

| | Dominant | Subdominant | Unambiguous |
|---|---|---|---|
| **Grade 2** | 1443 | 1484 | 1210 |
| **Grade 5** | 1150 | 1280 | 1011 |

*Table 3.* Mean time (ms) to reach 80% target fixation of Experiment 1 (Picture)

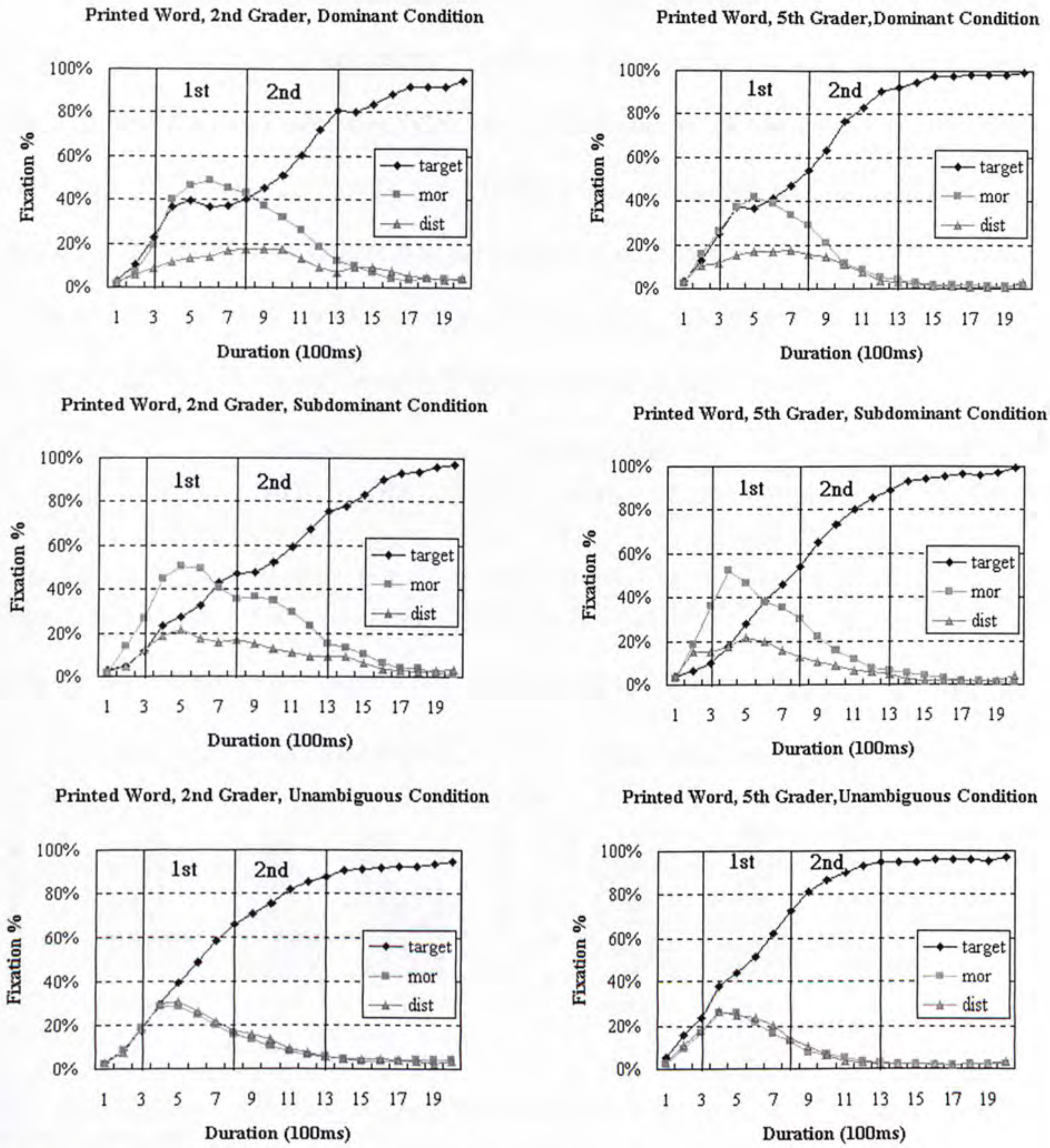



Note: DOM=Dominant, SUB=Subdominant, UNA=Unambiguous

*Figure 6.* Mean time (ms) to reach 80% target fixation in Picture session

*Experimental Session 2 (Printed Words)*

Similar analyses were conducted on Printed Words. The fixation curves, plotted in Figure 7, were remarkably different across conditions. In the Dominant and Unambiguous condition, fixations to all three regions were equally high at first, and the target popped out during or right after the first character is uttered. In the Subdominant condition, fixation to the morphemic distracter rose above the target in the first character stage, but such erroneous pattern was quickly reverted to normal as the second character was uttered, with a higher fixation on target and gradually subsiding fixations devoted to the distracters. Again, the general patterns of activation were similar across grades, but the target curves for 5$^{th}$ graders appeared to rise earlier and steeper than the 2$^{nd}$ graders.




Note: Target = The Correct Word, Mor =Morphemic Competitor, Dist=Unrelated Distracter

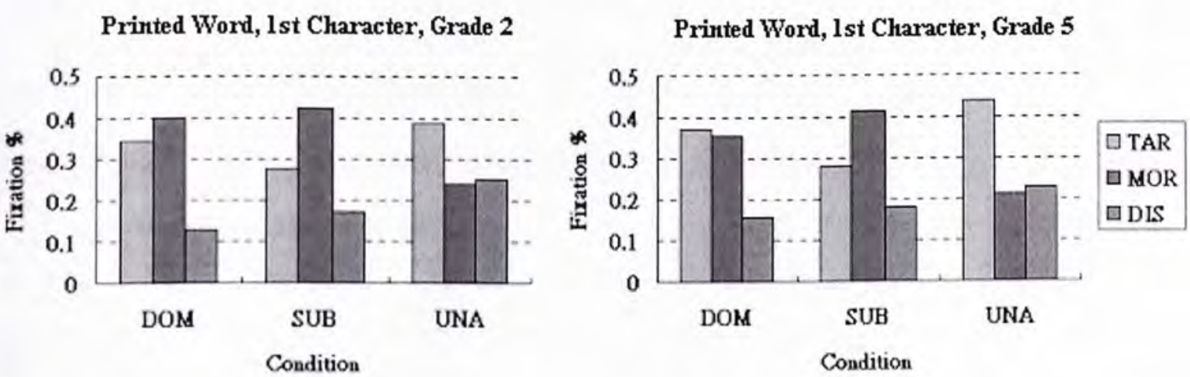
*Figure 7.* Overall fixation proportions of 2nd graders and 5th graders in Printed Word session

A three-way split-plot ANOVA, treating Condition (three levels) and Fixation Region (three levels) as within-subjects factors and Grade as the between-subjects factor, was conducted on fixation proportions in the first character stage (i.e. 300-800ms). Only the main effect of Region (*F(2,90) = 67.451, MSE = 3.969, p<.001*) and the Condition X Region interaction (*F(4,180) = 15.649, MSE = .727, p<.001*) reached significance. Post-hoc paired-sample t-tests revealed that for both the $2^{nd}$ and $5^{th}$ grader, fixation proportions were higher in the Unambiguous condition (*$2^{nd}$ grader: t(20) = 2.220, p<.05, $5^{th}$ grader: t(23) = 5.487, p<.001*), but the difference didn't exist in the Dominant Condition (*$2^{nd}$ grader: t(20) = -1.386, ns, $5^{th}$ grader: t(23) = .478, ns*). In line with visual inspections, the morphemic distracter attracted more fixations than the target in the Subdominant condition (*$2^{nd}$ grader: t(20) = -2.716, p<.05; $5^{th}$ grader: t(23) = -2.837, p<.01*). The mean fixation values and the corresponding bar charts are shown in Table 4 and Figure 8 respectively.

| | Dominant | | | Subdominant | | | Unambiguous | | |
|---|---|---|---|---|---|---|---|---|---|
| | **TAR** | **MOR** | **DIS** | **TAR** | **MOR** | **DIS** | **TAR** | **DIS** | **DIS** |
| **Grade 2** | 34.5% | 40.2% | 12.9% | 27.5% | 42.5% | 17.1% | 38.7% | 34.9% | 14.3% |
| **Grade 5** | 37.2% | 35.4% | 15.6% | 27.3% | 41.8% | 18.1% | 43.5% | 28.9% | 15.2% |

*Note: TAR=Target, MOR=Morphemic Distracter, DIS=Unrelated Distracter*

*Table 4.* Mean fixation proportion values of Experiment 2 (Printed Word), 1st character stage




Note: DOM=Dominant, SUB=Subdominant, UNA=Unambiguous, TAR=Target, MOR=Morphemic Distracter, DIS=Unrelated Distracter

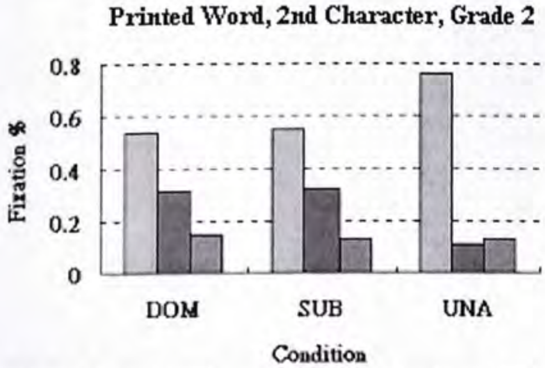
*Figure 8.* Mean fixation proportion values in Printed Word session, first character stage

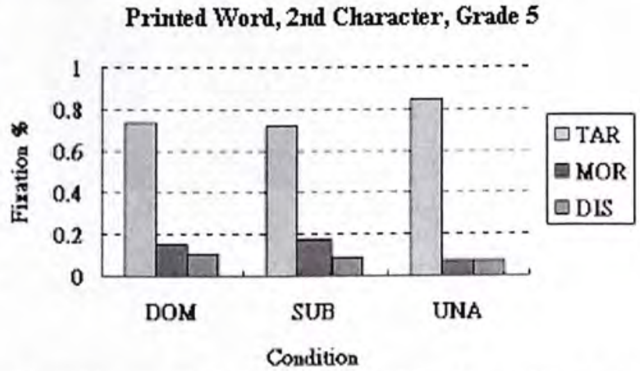
Another three-way split-plot ANOVA, treating Condition (three levels) and Fixation Region (three levels) as within-subjects factors and Grade as the between-subjects factor, was conducted on fixation proportions in the second character stage (i.e. 800-1300ms). In addition to the significant Region main effect (*F(2,90) = 648.955, MSE = 27.269, p<.001*), Region X Condition interaction (*F(2,90) = 30.357, MSE = 1.276, p<.001*) and Region X Grade interaction (*F(4,180) = 34.833, MSE = 1.724, p<.001*), there was a significant three-way Condition X Region X Grade interaction, *$F(4,180) = 3.124$, $MSE = .155$, $p<.05$*. Post-hoc tests revealed that at this stage, both 2nd and 5th graders were able to fixate at the target more than the morphemic distracter in the Dominant, *2nd grader: $t(20) = 4.729$, $p<.001$; 5th grader: $t(23) = 13.903$, $p<.001$*, Subdominant, *2nd grader: $t(20) = 3.566$, $p<.01$; 5th grader: $t(23) = 13.111$, $p<.001$* and Unambiguous conditions, *2nd grader: $t(20) = 20.395$, $p<.001$; 5th grader: $t(23) = 37.166$, $p<.001$*. However, when comparing the two grades on overall fixation proportions, 5th graders were found to fixate more on the target, *$t(43) = 6.117$, $p<.001$* and less on the morphemic distracter, *$t(43) = -5.726$, $p<.001$* and unrelated distracter *$t(43) = -3.099$, $p<.01$* than the 2nd graders, a phenomenon similar to the Picture session. Table 5 and Figure 9 present the respective fixation values in tabulated and graphical form.

| | Dominant | | | Subdominant | | | Unambiguous | | |
|---|---|---|---|---|---|---|---|---|---|
| | **TAR** | **MOR** | **DIS** | **TAR** | **MOR** | **DIS** | **TAR** | **DIS** | **DIS** |
| **Grade 2** | 53.8% | 31.3% | 14.8% | 54.8% | 32.1% | 13.1% | 76.0% | 10.6% | 13.1% |
| **Grade 5** | 73.0% | 15.8% | 10.6% | 71.2% | 17.9% | 9.0% | 84.4% | 7.7% | 7.9% |

*Note: TAR=Target, MOR=Morphemic Distracter, DIS=Unrelated Distracter*

*Table 5.* Mean fixation proportion values in Printed Word session, second character stage.




Note: DOM=Dominant, SUB=Subdominant, UNA=Unambiguous, TAR=Target, MOR=Morphemic Distracter, DIS=Unrelated Distracter

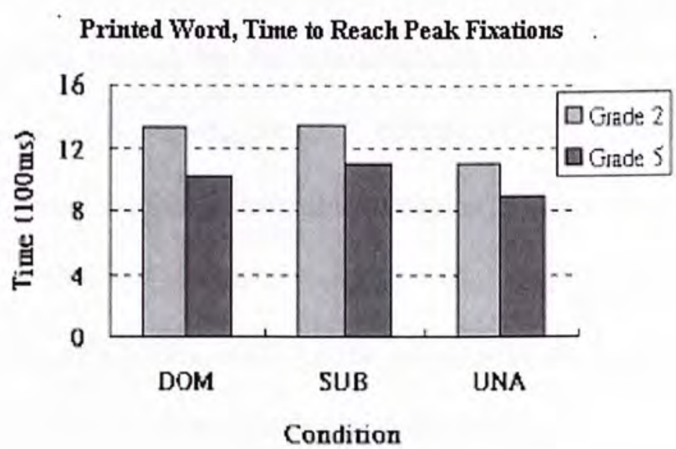
*Figure 9.* Mean fixation proportion values in Printed Word session, second character stage

A two-way split-plot ANOVA with Condition as the within-subjects factor and grade as the between-subjects factor was conducted on the time in which the target fixation reached 80%. The findings were very similar to the Picture session, with significant main effects of

Condition, $F(2, 90) = 21.420$, $MSE = 130.611$, $p<.001$ and Grade, $F(1, 45) = 28.073$, $MSE = 226.914$, $p<.001$, but not their interactions, $F(2, 90) = .932$, $MSE = 5.682$, *ns*. Fifth graders again needed less amount of time to reach the 80% fixation point. Results of post-hoc tests were again comparable to the Picture session, as the time needed was shorter in the Unambiguous condition than the Dominant, $t(43) = 4.375$, $p<.001$ and Subdominant conditions, $t(43) = 6.815$, $p<.001$. Grade difference was again observed when Dominant and Subdominant conditions were compared, revealing a marginally significant mean difference for 5th graders, $t(23) = 1.875$, $p < .10$ but not for 2nd graders, $t(20) = 0.313$, *ns*. The mean values and graphs of this measure are shown in Table 6 and Figure 10 respectively.

| | Dominant | Subdominant | Unambiguous |
|---|---|---|---|
| **Grade 2** | 1328 | 1346 | 1102 |
| **Grade 5** | 1021 | 1098 | 894 |

*Table 6.* Mean time (ms) to reach 80% target fixation in Printed Word session




Note: DOM=Dominant, SUB=Subdominant, UNA=Unambiguous

*Figure 10.* Mean time (ms) to reach 80% target fixation in Printed Word session

*Comparison between Picture and Printed Word session*

To see if there were differences in morphemic processing as a function of the stimulus used, split-plot ANOVAs, with the within-subjects factor of stimulus (i.e. Picture or Printed

Word) added, were conducted on fixations in the first character stage, fixations in the second character stage and also the time to reach 80% target fixations.

Of particular interest is the higher-order Stimulus related interactions in the first and second character stages. The four-way Stimulus X Condition X Region X Grade interaction was not significant in both stages. For three-way interactions, there was a significant Stimulus X Condition X Region interaction in both the first character, $F(4,180) = 5.100$, $MSE = .223$, $p<.001$, and second character stage, $F(4, 180) = 5.797$, $MSE = .326$, $p<.001$. As the Condition X Region interactions were also significant when Picture and Printed Word sessions were separately analyzed, further post-hoc analyses were performed to figure out the source of this three-way interaction. Data of both grades were combined and pair-sampled t-tests with Stimulus as the within-subject factor were conducted. The key finding was that fixations proportions to the morphemic distracter in Picture Session were lower than the Printed Word Session at the first character stage (*Dominant*, $t(45) = -4.671$, $p<.001$, *Subdominant*, $t(45) = -3.076$, $p<.01$), but the reverse pattern was observed at the second character stage (*Dominant*, $t(45) = 2.842$, $p<.01$, *Subdominant*, $t(45) = 2.095$, $p<.05$).

Furthermore, we found a significant Stimulus X Region X Grade interaction in the first character stage only, $F(4, 180) = 4.138$, $MSE = .093$, $p<.05$. The origin of such interaction can be easily located, as significant Region X Grade interactions were found in Picture but not the Printed Word session. To recap, the origin of Region X Grade interactions in the Picture session were due to 5$^{th}$ graders having higher proportions of fixations towards the morphemic distracter at the first character stage.

Regarding the time to reach peak target fixations, children needed less time to process Printed Words than Pictures, $F(1, 45) = 15.957$, $MSE = 121.263$, $p<.001$. No interactions were significant, as the effect size was around 100ms regardless of Conditions or Grade.

# Character 4: Discussion

The major goal of the present study is to establish the validity of a new experimental paradigm for tapping morphemic processing in children. Another objective is to provide process-oriented accounts on influences of morphemes in Chinese language acquisition, which can also inform the findings of studies using the "awareness" approach. Grade differences in morphemic ambiguity resolution are interpreted, and our children's data are also verified against extant adult models on morphemic ambiguity resolution and speech processing. Finally, stimulus differences in morphemic processing are addressed.

## *Reliability and Validity of the Measure*

In general the patterns of eye-movements of both 2$^{nd}$ and 5$^{th}$ graders were reliable enough to be interpreted in a theoretical sense. Generally children saw what they heard and made correct responses at the end of a trial. Fixation proportions to the target slowly rose to the peak as the spoken word was gradually unfolded, while those to distracters gradually dropped to nil. This confirmed the linking hypothesis stipulated by Allopenna et al. (1998), which also predicted stepwise increments of fixations towards targets as a function of time.

Fixation behaviors of both 2$^{nd}$ and 5$^{th}$ graders in the Visual World Paradigm were clearly influenced by the morphological structure of the spoken word, as shown by the highly significant interactions between Condition and Region in both sessions and the differential fixation patterns between the Dominant and Subdominant condition. Like previous studies, these language-mediated eye movements provided evidence to show the sensitivity of the Visual World Paradigm in tapping the linguistic processes being examined, which, in the present study is the processing of morphemes. The need to resolve ambiguities has appreciably lengthened the recognition time of words that map onto two alternative morphemes (i.e. as in Dominant or Subdominant condition), as indicated by their delay in reaching peak fixations to the target in the experimental conditions. These findings suggested that both our 2nd and 5th graders are capable of decomposing words into units of morphemes, which also converged with findings in previous literacy researches. For example, when morphological awareness tasks were orally administered, Mcbride-Chang et al. (2003) found near ceiling performance for 2nd graders, whilst some other studies reported that even kindergarteners could reach around 50% accuracy rate (e.g. Chow & Chow, 2005; Mcbride-Chang et al., 2005b). When written tests were used in other studies, performance of 2nd graders dropped but was still well above chance level (e.g. Ku & Anderson, 2003; Wang, et al. 2006). Therefore, it appears plausible to argue that the capability of processing morphemes in the brain, revealed in the present study, can lead to the conscious awareness to perform literacy tasks accurately, as demonstrated in previous studies.

*Grade Differences in Morphemic Processing*

Though both 2nd graders and 5th graders were capable of analyzing words at the morphemic level, they differed in terms of the efficiency of morphemic processing. With an online measure, the present study allows this dimension to be explored, as we found that 5th graders were more competent than the 2nd graders in suppressing fixations to the morphemic distracter. This is confirmed by both visual inspections of fixation curves and post-hoc tests, which showed that 5th graders had lower amount of fixations towards the morphemic distracter in the second character stage, regardless of the stimuli used. We believe that the high fixations devoted to the morphemic competitor reflect the "cost" of morphemic processing, that is, the need to resolve temporary ambiguities. Ambiguity situation is seldom encountered if whole-word awareness is used, as the sound-meaning mapping is often one-to-one (An exceptional case would be "mo5 yue5", which can mean "Mother-tongue", "Breast-feeding" or "No rain" in Cantonese). However, if the word is to be analyzed at the morphemic level, utterance of the first character will often trigger the activation of many other competitor morphemes sharing the same sound, resulting in a temporarily ambiguous situation. As the second character is uttered, the child would then need to utilize this contextual information and select the appropriate morpheme, while inhibiting all other previously activated competitors, so that they would not obscure understanding of the target word. Some empirical findings using experimental tasks are in line with our claim. Their results are illustrated below.

For example, Nation et al. (2003) also adopted the Visual World Paradigm and revealed that less skilful children readers could activate the target as readily as the skilful readers, but had problems inhibiting other distracters, a pattern very similar to the present findings. Gernsbacher and Frust (1991) also yielded converging evidence with college students. In addition to reading proficiency, selective attention also plays a crucial role in response inhibition. For example, Wildernberg and Molen (2004) had 7-year-olds, 10-years-olds and young adults perform a few selective inhibition tasks. Each time an arrow pointed to either one of the two buttons, and subjects were asked to either press the button that the arrow pointed to, or another button, yielding either a compatible or incompatible condition. Their study revealed a clear developmental trend of selective inhibition skills. Adults performed far better than the 10-years-olds, who also outperformed the 7-years-olds in all variations of the task, and the effect size of compatibility was bigger for the younger children than older children or adults, indicating that incompatible responses were more costly to the younger children. . Besides behavioral studies, Klimkeit, Mattingley, Sheppard, Farrow and Bradshaw (2005) also reported in their brain-imaging study some neural correlates of attention development. They believed that attention and executive function skills were both associated with the development of frontal lobe, which undergoes a major developmental spurt between the age of 7 and 10. In conclusion, these findings purported to indicate that grade differences in activations to morphemic distracters could be attributable to both reading proficiency and cognitive skills, both of which were poorer for the 2nd graders.

The inhibition account can also accommodate the significant grade difference in fixations to the unrelated distracter in the second character stage. However, the effect size was considerably smaller than that of the morphemic distracter. Such attenuations in grade differences are attributable to the amount of contextual information available for inhibition. While both characters served as contextual information to eliminate the unrelated distracter, only the second character provided the context to disambiguate the morphemic distracter. For the 2nd graders, it appears plausible that more contextual information can boost their efficiency in inhibiting distracters. This argument is in accord with Chen, Song, Lau, Wong and Tang (2003), who discovered that 2nd graders adopted a more word-dependent strategy in reading Chinese, but such strategy is no longer deemed necessary as children became more automatic in character recognition. We therefore suggest that grade differences in inhibition of competitors may vary as a function of the contextual information available, though it still awaits future studies employing sentential contexts (e.g. Tsang, 2006) to verify the claim.

One additional source of grade difference in efficiency needs to be mentioned. It was found that the time taken to reach peak activation for the target word was shorter for 5th graders than 2nd graders, irrespective of the conditions and testing stimuli used. The interpretation was rather trivial, though. As the stimulus used was catered at the 2nd grade level, 5th graders have greater amount of exposures towards these words, hence they can be more readily retrieved. Converging evidences can also be gleaned from Chen et al. (2003) eye-movement study, which revealed decreasing fixation durations to words as a function of grade, indicating faster retrieval from the mental lexicon. Indeed, such grade difference appears to be independent of the morphemic properties of the word, as the effect size in the Unambiguous condition was comparable to the experimental conditions, and no significant interaction effects with Conditions were found.

As efficiency of morphemic processing is taken into account, the present study also sheds some light towards explaining the grade differences observed in previous researches using the "awareness" approach (e.g. Li, et al., 2002; Ku & Anderson, 2003; Mcbride-Chang, et al. 2003). As these researchers were predominately focused on the predictive validity of their tasks in reading development, grade differences in accuracy were often given little attention, and were often simply interpreted as "increasing reading experience". The present study has stressed the need to ponder into the systematic influences on grade differences, such as constraints in cognitive skills and use of contextual information in reading.

*Mechanisms of Morphemic Ambiguity Resolution and Speech Processing in Children*

After issues regarding grade differences in morphemic processing are dealt with, this section attempts to unleash the mental procedures of resolving morphemic ambiguities and processing spoken texts in Chinese children. The children data are contrasted against Tsang's (2006) adult data and extant adult models.

The first experiment of the present study is a replication of Tsang's (2006) first experiment on university students, hence allowing a direct comparison between their data and our children data. Similar to Tsang, manipulations of morphemic dominance elicited differential fixation patterns between the Dominant and Subdominant condition in both the 2nd and 5th graders. However, the frequency effect appeared much less salient than the adult data. In Tsang's study, the more frequent morpheme attracted substantially higher amount of fixations in both the Dominant and Subdominant condition, while in the present study, such pattern could be observed in the Dominant condition only. Visual inspections of the fixation curve revealed that even in the Dominant condition, activations of the morphemic distracter continued to soar up to around 40%, until contextual information is provided in the second character stage for ambiguity resolution. Such patterns were not observed in adults, whose fixations to morphemic distracter never exceeded 30% and were clearly separable from the target from beyond the 500ms time-window, when the first character was still being uttered. Of the several theoretical models on ambiguity resolution, Tsang claimed that his data fit well with the reordered access model (Duffy et al., 1988; Rayner & Duffy, 1986), which predicted activations of both the dominant and subdominant meanings, though the subdominant one to a lesser extent. Contextual information then deferred the integration of the incorrect meaning, and eventually the target meaning pops out. In contrast, it seems that young children in the present study initially adopted what Swinney (1979) proposed as an exhaustive access model, that is, both meanings were activated to the same degree at first. Only when contextual information is provided later, can they eliminate the incorrect one. With increasing years of experience in the language, the morphemic dominance effect gradually emerges, and they shift to using reordered access in resolution. Indeed, our 5$^{th}$ graders are on the verge of showing adult-like patterns of resolution, as shown by their faster time to reach peak fixation in the Dominant condition than the Subdominant condition in both experimental sessions. The morphemic dominance effect, though quite weak for the 5$^{th}$ graders, sill facilitated their recognition of the target word in the Dominant condition.

Having understood the processes of morphemic access and ambiguity resolution in children, the next issue concerns about how morphemes are represented in the children's mental lexicon, which remains a hot debate in the adult's literature to date (see Frost, Grainger & Rastle, 2005). Taft and Kougious (2004) recently argued that the meaning of separate morphemes like "教" exists in the semantic representational level, but that a separate level of representation for these morphemes is not necessary. Based on his adult findings, Tsang (2006) refuted such assertions and instead constructed a model that delineated the role of a separate modality-free morphemic layer in the mental lexicon. He suggested that only this modified model could handle the frequency effect produced in his study. In the present study, while children were able to analyze words in morphemic units, the morphemic dominance effect was not robust. Therefore we speculate that the morphemic representational level was not yet fully developed in young children. According to proponents of interactive-activation models (e.g. McClelland & Rumelhart, 1981), priming occurs if the concept receives excitatory signals from either lower or upper levels of representation. Therefore, morphemic priming can only occur when a lower level of morphemic representation level is present.

Finally, implications of the present study to the spoken word recognition models were addressed. Cohort selection models like the TRACE (McClelland & Elman, 1986) have been widely accepted in the adult literature to date, and Tsang's (2006) recent findings further provided the empirical ground that these models also applied to Chinese. Two features of the TRACE model are highlighted with respect to the generalizability of these models to Chinese children. First, regarding the interactive nature of the model, we speculated that young children were poorer in inhibiting irrelevant cohorts, particularly the one that shared orthographic information. Hence, it can be argued that while partial information activates a bunch of cohorts in their lexicon, they are slow to isolate the target from the cohort set. Second, regarding the process of mapping, both our 2$^{nd}$ and 5$^{th}$ graders seemed able to map the acoustic signal to its meaning in a continuous manner in the absence of ambiguous morphemes. This assertion is based on the findings that their fixation curves to the target were gradually increasing throughout the entire course of the utterance. However, 2$^{nd}$ graders were less able to achieve continuous mapping when there were ambiguous morphemes, as we saw brief periods of stagnation in their fixation curves. The delay usually came right after the first character had been uttered. Apparently this was not due to poor phonological awareness, as if that is true, we should have got the stagnation patterns in the unambiguous condition. We therefore conclude that for the 2nd grader, it is the process of morphemic ambiguity resolution that demands huge mental resources and consequently leads to a momentary halt in the mapping process. Stagnations in fixation curves were not evident in 5th graders, as the ambiguity resolution processes have become rather automatic for them and consumed only minimal mental resources.

*Stimulus Differences*

The major goal of using printed words as stimulus in the Visual World Paradigm is to examine if there are systematic interactions between orthographic and morphemic processes.

When printed text was used, children of both grades were approximately 100ms faster in recognizing the same word than in the picture condition. This finding is consistent with our initial prediction, as presentation of printed texts restricted morphemic competitions to homophones that only share the same orthography, children need less time to suppress irrelevant activations, hence leading to faster overall processing.

With regard to qualitative differences in morphemic processing, we didn't get any significant interactions between Stimulus, Condition and Grade. Therefore, despite the fact that 2nd graders have less experience with printed texts, and hence poorer orthographic skills, they are just as able as their older peers in utilizing the "morphemic" mode of processing when printed texts are encountered. Hence, orthographic and morphemic processes appear to be independent of each other. This stands in contrast to the assertion of researchers adopting the "awareness" approach, who suggested that awareness to the semantic radical of the character, which is modality specific and must be linked with orthographic skills, also contributed as part of morphological awareness (e.g. Nagy, et al., 2002; Shu & Anderson, 1997). However, as mentioned in the Introduction, compounding morphologies best characterize the rule of forming words in the Chinese language, hence we believe that morphological awareness in children should be tapped at the character-to-word level, rather than within-character level.

On the other hand, we got significant interactions between Stimulus, Condition and Region at both character stages. Recall that the interactions were due primarily to the differential fixation patterns towards the morphemic distracters in the two sessions. At the first character stage, the morphemic distracter received higher amount of fixations in the Printed Word session, which seemed to suggest a more prominent interference effect of words than pictures. However, we cast doubt on whether these influences are systematic in nature, as we concluded previously that without contextual information available for disambiguation at this stage, children were reluctant to commit to any choice of morphemes, hence they merely looked at the target and morphemic distracter in a random manner. The reverse pattern was observed at the second character stage, as the morphemic distracter attracted less fixations in the Printed Word session. At this stage, the children's task is to make use of contextual information (i.e. the second character) and inhibit all other irrelevant information as soon as possible. As provision of orthographic information reduces the number of homophonic competitors, children were better able to suppress fixations to morphemic distracter in this session.

The use of printed texts in the Visual World Paradigm to tap morphemic processing has been tested solely in children, who are still on the verge of achieving full linguistic competence. Hence, any systematic influences between orthographic and morphemic processing should be further verified with adult data, so that the prototypical pattern of activations for "printed texts" can be identified.

## Chapter 5: Conclusion

### *Theoretical and Methodological Contributions*

Taken together, the present study has enriched our understanding on the influence of morphemes in Chinese language acquisition from a "processing" vantage point, rather than an "outcome-based" perspective as in previous studies on morphological awareness. A few major implications are summarized below.

Regarding the age of acquisition, the present study revealed that the capability to process Chinese words at the morphemic level is already in place as children begin elementary schooling, and it appears to be independent of their orthographic skills in written text. Despite the early acquisition, the efficiency in utilizing the skill in reading was found to vary across elementary grade levels, which were attributable to both reading proficiency and selective attention skills. The efficiency dimension of morphemic processing was seldom mentioned by literacy researchers, who stressed the ultimate benefits of utilizing the "morphemic" mode but overlooked the difficulties that children must encounter when mastering the skill. The present study demonstrated that the need to resolve morphemic ambiguities would severely stall the word recognition processes of younger children, though provision of contextual cues may help to alleviate the difficulties.

The present study also provides a developmental vantage point for the theoretical models in adult morphemic processing and spoken word recognition. Our findings indicated that the morphemic dominance effect is not robust in children. Both meanings are activated to similar extents in young children, and they have to rely mainly on contextual information in morphemic processing. Adult-like frequency effect gradually takes precedence as children gain more language experience. Provision of orthographic information may slightly alter the mechanisms of morphemic ambiguity resolution, but adult data are needed to justify the claims. Regarding the issues of how morphemes are represented in the lexicon, the present study suggested that meanings of morphemes might exist in the semantic layer in young children's lexicon, though a separate morphemic layer wouldn't emerge until the age of adolescence. Assumptions of the TRACE model generally held in Chinese children, but young children may not have well-developed inhibitory linkages in their lexicon, and whilst they were capable of continuous mapping the acoustic signal to the meaning, the need to resolve morphemic ambiguities may temporarily suspend such processes.

Besides the theoretical implications, this study also offers methodological contributions to the field of language development. Ever since the need to tap the role of morphemes in Chinese language acquisition is recognized, literacy researchers had long been seeking a valid and reliable measure to fulfill the need (Ku & Anderson, 2003; Wang, 1999). The success of the present study has firmly established the reliability and validity of eye-movement measures in tapping morphemic processing in children. The eye-movement and "Visual World" duo can also be adopted to tap many other linguistic processes in children, such as phonological and syntactic processes, to name but a few. It appears plausible that literacy researchers should embrace this paradigm to supplement their offline tasks in future.

*Limitations and Future Directions*

One limitation of the present study is the confined children cohort being explored. As only two age groups of kids are chosen, the complete trajectory on how children of different ages resolve morphemic ambiguities is yet to be fully unveiled. For example, the age at which the ability to process morphemes emerges, as well as the age at which adult-like efficiency in morphemic processing is achieved, is still not known. Future researches should incorporate the same paradigm to different age clusters, such as preschool children or early adolescence, to address these issues. Individual differences in morphemic processing would be another exciting area that deserves further investigations. The capability and efficiency of processing may vary as a function of reading proficiency and general cognitive skills. Shu et al. (2006) recently discovered that performance of dyslexic and age-matched normal kids on literacy tasks differed substantially. It would certainly be worthwhile to seek converging evidences from online measures.

Another area that the present study did not cover is on influences of prior contexts on morphemic processing. In daily life words are rarely comprehended in isolation, as they are often preceded by prior contexts, which provide cues to select the appropriate morpheme. For example, Nation et al. (2003) found that a thematic verb was enough to constrain subsequent meaning access in 11-year-old English-speaking children, though the effect was less prominent for less-skilled readers. With respect to morphemic processing, Tsang (2006) also discovered in their Chinese adults that a prior sentential context could constrain access to the context-appropriate morpheme well before the target word was uttered, even when the less frequent morpheme was called for. Duffy & Keir (2004) got similar results in English when a discourse context is used. It will be interesting to explore how contextual effects would interact with morphemic processing in different age groups of children.

Last but not least, the practical significance of the present study has yet to be fully revealed. Whether, when and how "morphemes" should be taught in the Chinese lesson is still an under-explored issue. The few training programs reported in previous studies (e.g. Wang, 1999; Nagy, et al., 2002; Packard, et al., 2006) were developed with little theoretical guidance, and the pedagogies were often reported vaguely (e.g. asking probing questions about word meanings). While the present study provides some clues that providing training in the use of contextual cues and attention skills may boost the efficiency of morphemic processing, more applied researches should be conducted to inform the specific instructional strategies to be adopted.

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# Appendix

## Stimulus Materials (bolded items were targets)

| List 1 | | | | | |
|---|---|---|---|---|---|
| Ambiguous Set | | | | | |
| Dominant Target | | Subdominant Target | | Unrelated Distracter | |
| **1. 教師 (teacher)** | **gaau3 si1** | 教堂 (church) | gaau3 tong2 | 排球 (volleyball) | paai4 kau4 |
| **2. 火柴 (matches)** | **foh2 chaai4** | 火車 (train) | foh2 che1 | 雪人 (snowman) | suet3 yan4 |
| **3. 提琴 (violin)** | **tai4 kam4** | 提子 (grape) | tai4 ji2 | 花朵 (flower) | fa1 doh2 |
| **4. 公園 (park)** | **gung1 yuen2** | 公雞 (cock) | gung1 gai1 | 波浪 (wave) | boh1 long6 |
| **5. 日曆 (calendar)** | **yat6 lik6** | 日出 (sunrise) | yat6 chut1 | 小丑 (clown) | siu2 chau2 |
| **6. 波浪 (wave)** | **boh1 long6** | 波鞋 (shoe) | boh1 haai4 | 南瓜 (pumpkin) | naam4 gwa1 |
| **7. 煙頭 (smoke)** | **yin1 tau2** | 煙花 (firework) | yin1 fa1 | 滑梯 (slide) | waat6 tai1 |
| **8. 粉麵 (noodle)** | **fan2 min3** | 粉筆 (chalk) | fan2 bat1 | 公雞 (cock) | gung1 gai1 |
| 9. 小孩 (child) | siu2 haai4 | **小丑 (clown)** | **siu2 chau2** | 火箭 (rocket) | foh2 jin3 |
| 10. 曲譜 (sheet) | kuk1 po2 | **曲線 (curve)** | **kuk1 sin3** | 和尚 (monk) | wo4 seung2 |
| 11. 月亮 (moon) | yuet6 leung6 | **月台 (platform)** | **yuet6 toi4** | 神仙 (angel) | san4 sin1 |
| 12. 花朵 (flower) | fa1 doh2 | **花灑 (shower)** | **fa1 sa2** | 教師 (teacher) | gaau3 si1 |
| 13. 雪人(snowman) | suet3 yan4 | **雪糕 (ice-cream)** | **suet3 go1** | 太陽 (sun) | taai3 yeung4 |
| 14. 滑梯 (slide) | waat6 tai1 | **滑鼠 (mouse)** | **waat6 sue2** | 月亮 (moon) | yuet6 leung6 |
| 15. 銀包 (purse) | ngan4 baau1 | **銀河 (galaxy)** | **ngan4 ho4** | 日曆 (calendar) | yat6 lik6 |
| 16. 光線 (light) | gwong1 sin3 | **光頭 (bald)** | **gwong1 tau4** | 提子 (grape) | tai4 ji2 |
| Unambiguous Set | | | | | |
| Dominant Control | | Subdominant Control | | Unrelated Distracter | |
| 17. 信封(envelope) | shun3 fung1 | **芝士 (cheese)** | **ji1 si2** | 銀包 (purse) | ngan4 baau1 |
| 18. 電話 (phone) | din6 wa2 | **雨傘 (umbrella)** | **yue5 saan3** | 白兔 (rabbit) | baak6 to3 |
| 19. 麵包 (bread) | min6 baau1 | **花生 (peanut)** | **fa1 sang1** | 電話 (telephone) | din5 wa2 |
| 20. 錢包 (purse) | chin4 baau1 | **獅子 (lion)** | **si1 ji2** | 粉筆 (chalk) | fan2 bat1 |
| 21. 雷電 (thunder) | lui4 din6 | **衣服 (clothes)** | **yi1 fuk6** | 南瓜 (pumpkin) | naam4 gwa1 |
| 22. 糖果 (candy) | tong4 gwo2 | **蜜蜂 (bee)** | **mat6 fung1** | 耳朵 (ear) | yi5 doh2 |
| 23. 風箏 (kite) | fung1 jang1 | **筷子 (chopstick)** | **faai3 ji2** | 火車 (train) | foh2 che1 |
| 24. 掃巴 (sweep) | so3 ba2 | **老鼠 (mouse)** | **lo5 sue2** | 牙齒 (tooth) | nga4 chi2 |
| **25. 椅子 (chair)** | **yi2 ji2** | 鋼琴 (piano) | gong3 kam4 | 泳池 (pool) | wing2 chi4 |
| **26. 星星 (star)** | **sing1 sing1** | 香蕉 (banana) | heung1 jiu1 | 老虎 (tiger) | lo5 foo2 |
| **27. 白飯 (rice)** | **baak6 faan6** | 老虎 (tiger) | lo5 foo2 | 麵包 (bread) | min6 baau1 |
| **28. 尾巴 (tail)** | **mei5 ba1** | 猴子 (monkey) | hau4 ji2 | 花生 (peanut) | fa1 sang1 |
| **29. 長城(city-wall)** | **cheung4 sing4** | 白兔 (rabbit) | baak6 to3 | 信封 (envelope) | shun3 fung1 |
| **30. 南瓜(pumpkin)** | **naam4 gwa1** | 企鵝 (penguin) | kei5 ngoh2 | 大象 (elephant) | daai6 jeung6 |
| **31. 芝士 (cheese)** | **ji1 si2** | 課室 (classroom) | foh3 sat1 | 老鼠 (mouse) | lo5 sue2 |
| **32. 毛蟲 (worm)** | **mo4 chung4** | 耳朵 (ear) | yi5 doh2 | 尾巴 (tail) | mei5 ba1 |

| List 2 | | | | | |
|---|---|---|---|---|---|
| Ambiguous Set | | | | | |
| Dominant Target | | Subdominant Target | | Unrelated Distracter | |
| 1. 教師 (teacher) | gaau3 si1 | **教堂 (church)** | **gaau3 tong2** | 排球 (volleyball) | paai4 kau4 |
| 2. 火柴 (matches) | foh2 chaai4 | **火車 (train)** | **foh2 che1** | 雪人 (snowman) | suet3 yan4 |
| 3. 提琴 (violin) | tai4 kam4 | **提子 (grape)** | **tai4 ji2** | 花朵 (flower) | fa1 doh2 |
| 4. 公園 (park) | gung1 yuen2 | **公雞 (cock)** | **gung1 gai1** | 波浪 (wave) | boh1 long6 |
| 5. 日曆 (calendar) | yat6 lik6 | **日出 (sunrise)** | **yat6 chut1** | 小丑 (clown) | siu2 chau2 |
| 6. 波浪 (wave) | boh1 long6 | **波鞋 (shoe)** | **boh1 haai4** | 南瓜 (pumpkin) | naam4 gwa1 |
| 7. 煙頭 (smoke) | yin1 tau2 | **煙花 (firework)** | **yin1 fa1** | 滑梯 (slide) | waat6 tai1 |
| 8. 粉麵 (noodle) | fan2 min3 | **粉筆 (chalk)** | **fan2 bat1** | 公雞 (cock) | gung1 gai1 |
| **9. 小孩 (child)** | **siu2 haai4** | 小丑 (clown) | siu2 chau2 | 火箭 (rocket) | foh2 jin3 |
| **10. 曲譜 (sheet)** | **kuk1 po2** | 曲線 (curve) | kuk1 sin3 | 和尚 (monk) | wo4 seung2 |
| **11. 月亮 (moon)** | **yuet6 leung6** | 月台 (platform) | yuet6 toi4 | 神仙 (angel) | san4 sin1 |
| **12. 花朵 (flower)** | **fa1 doh2** | 花灑 (shower) | fa1 sa2 | 教師 (teacher) | gaau3 si1 |
| **13. 雪人 snowman)** | **suet3 yan4** | 雪糕 (ice-cream) | suet3 go1 | 太陽 (sun) | taai3 yeung4 |
| **14. 滑梯 (slide)** | **waat6 tai1** | 滑鼠 (mouse) | waat6 sue2 | 月亮 (moon) | yuet6 leung6 |
| **15. 銀包 (purse)** | **ngan4 baau1** | 銀河 (galaxy) | ngan4 ho4 | 日曆 (calendar) | yat6 lik6 |
| **16. 光線 (light)** | **gwong1 sin3** | 光頭 (bald) | gwong1 tau4 | 提子 (grape) | tai4 ji2 |
| Unambiguous Set | | | | | |
| Dominant Control | | Subdominant Control | | Unrelated Distracter | |
| **17. 信封(envelope)** | **shun3 fung1** | 芝士 (cheese) | ji1 si2 | 銀包 (purse) | ngan4 baau1 |
| **18. 電話 (phone)** | **din6 wa2** | 雨傘 (umbrella) | yue5 saan3 | 白兔 (rabbit) | baak6 to3 |
| **19. 麵包 (bread)** | **min6 baau1** | 花生 (peanut) | fa1 sang1 | 電話 (telephone) | din5 wa2 |
| **20. 錢包 (purse)** | **chin4 baau1** | 獅子 (lion) | si1 ji2 | 粉筆 (chalk) | fan2 bat1 |
| **21. 雷電 (thunder)** | **lui4 din6** | 衣服 (clothes) | yi1 fuk6 | 南瓜 (pumpkin) | naam4 gwa1 |
| **22. 糖果 (candy)** | **tong4 gwo2** | 蜜蜂 (bee) | mat6 fung1 | 耳朵 (ear) | yi5 doh2 |
| **23. 風箏 (kite)** | **fung1 jang1** | 筷子 (chopstick) | faai3 ji2 | 火車 (train) | foh2 che1 |
| **24. 掃巴 (sweep)** | **so3 ba2** | 老鼠 (mouse) | lo5 sue2 | 牙齒 (tooth) | nga4 chi2 |
| 25. 椅子 (chair) | yi2 ji2 | **鋼琴 (piano)** | **gong3 kam4** | 泳池 (pool) | wing2 chi4 |
| 26. 星星 (star) | sing1 sing1 | **香蕉 (banana)** | **heung1 jiu1** | 老虎 (tiger) | lo5 foo2 |
| 27. 白飯 (rice) | baak6 faan6 | **老虎 (tiger)** | **lo5 foo2** | 麵包 (bread) | min6 baau1 |
| 28. 尾巴 (tail) | mei5 ba1 | **猴子 (monkey)** | **hau4 ji2** | 花生 (peanut) | fa1 sang1 |
| 29. 長城 (city wall) | cheung4 sing4 | **白兔 (rabbit)** | **baak6 to3** | 信封 (envelope) | shun3 fung1 |
| 30. 南瓜(pumpkin) | naam4 gwa1 | **企鵝 (penguin)** | **kei5 ngoh2** | 大象 (elephant) | daai6 jeung6 |
| 31. 芝士 (cheese) | ji1 si2 | **課室 (classroom)** | **foh3 sat1** | 老鼠 (mouse) | lo5 sue2 |
| 32. 毛蟲 (worm) | mo4 chung4 | **耳朵 (ear)** | **yi5 doh2** | 尾巴 (tail) | mei5 ba1 |